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Density and Viscosity of Saturated Liquid Dimethoxymethane from (218.15 to 383.15) K

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The density and viscosity of saturated liquid dimethoxymethane were measured over the temperature range from (218.15 to 383.15) K with a vibrating-tube densimeter and a calibrated Ubbelohde-type capillary viscometer, respectively. The estimated uncertainties of the measurements were ±1.0 kg/m^3 for density and ±1.8% for viscosity. Density results were fitted using the polynomial with an absolute average deviation of 0.13% and a maximum deviation of 0.22% from the correlated equation. Viscosity results were correlated as a function of temperature. The absolute average deviation and the maximum deviation of the experimental viscosity results from the correlated equation are 0.45% and 1.07%, respectively.

1. Introduction

As petroleum resources become depleted and environmental pollution becomes more serious, especially in developing countries, it becomes an urgent problem to find and develop new alternative clean fuels. In recent research, it was founded that using dimethoxymethane ($CH_3-O-CH_2-O-CH_3$) as a fuel additive can greatly improve diesel oil and petrol combustion properties.[1,2] Furthermore, it has a large oxygen content (42% by mass) and is miscible with diesel fuel, hence it is regarded as a good fuel additive and a potential alternative fuel in the future. In addition, dimethoxymethane is also extensively used as a solvent in household and industrial sprays, as a blowing agent for polyurethane foam, and in the production of ion-exchange resins. High-purity dimethoxymethane is also used in cosmetics and pharmaceuticals. In those applications, the thermophysical property data of dimethoxymethane is important, but there is little data in the literature. In our previous work,[3] the thermal conductivity of liquid dimethoxymethane was measured. In this work, the density of dimethoxymethane has been measured with a vibrating-tube densimeter in the temperature range from (233.15 to 363.15) K and the viscosity has been measured with a sealed gravitational capillary viscometer in the temperature range from (218.15 to 383.15) K.

2. Experimental Section

The sample of dimethoxymethane was provided by Shanghai Yongfu Fine Chemical Co. Ltd. Before the experiment, the sample was further purified with sodium and distillation. Finally, the purity was analyzed with an Agilent 6890N gas chromatograph using a TCD detector; the results indicated that the mass purity of the sample was better than 99.4%.

Measurements were made in a thermostated bath whose temperature could be varied from (210 to 500) K, and the temperature stability of the bath was better than ±5 mK·h^{-1}. The temperature was measured with a standard platinum resistance thermometer and an ASL F18 resistance thermometry bridge. The combined standard uncertainty of the temperature for the viscosity and density measurements was less than ±10 mK (ITS-90). Details concerning the thermostated bath and the temperature measurement have been described in refs 4 and 5.

Density Measurement. The liquid density of dimethoxymethane was measured by our newly developed vibrating-tube densimeter.[6] The principle of the vibrating-tube densimeter is based on a constant relation between the density, ρ, of a fluid inside the vibrating tube and the vibration period, τ. In this work, the vibration period of the U-shaped tube was measured with the Keithley 2010 digital multimeter using the frequency and period function. Finally, the density of the fluid was obtained with the vibration period through the equation

$$\rho = A\tau^2 - B \tag{1}$$

where the constants A and B were determined with reference fluids for which there was highly accurate density data. In this work, ethanol and toluene were used as calibration fluids in the temperature range from (233.15 to 298.15) K. Water and toluene were used as calibration fluids in the temperature range from (303.15 to 363.15) K. Because of the tube dilation and temperature dependence of the elastic modulus of the material, constants were determined at each temperature. The uncertainties of the density results were estimated to be less than ±1.0 kg/m^3.

Viscosity Measurement. The viscosity of dimethoxymethane was measured with a sealed gravitational capillary viscometer.[7] According to the Hagen−Poiseuille equation that accounts for the kinetic energy correction and end correction, the kinematic viscosity v of the fluid can be calculated from

$$v = \frac{\eta}{\rho_L} = kAt - \frac{B}{t} \tag{2}$$

where t is the flow time, η is the dynamic viscosity, ρ_L is the liquid density, k is the vapor buoyancy correction that

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Table 1. Experimental Density Values for Saturated Liquid Dimethoxymethane

T/K	ρ_{exptl}/kg·m^{-3}	$(\rho_{\mathrm{exptl}} - \rho_{\mathrm{calcd}})/\rho_{\mathrm{calcd}}$ /%
233.16	935.5	−0.19
243.16	923.8	−0.05
253.16	912.4	0.13
263.15	899.6	0.18
273.15	886.0	0.15
283.15	872.3	0.12
293.15	858.1	0.05
303.15	842.8	−0.12
313.15	827.9	−0.22
323.16	814.1	−0.16
333.15	800.0	−0.09
343.15	785.2	−0.06
353.16	770.8	0.08
363.11	755.9	0.20

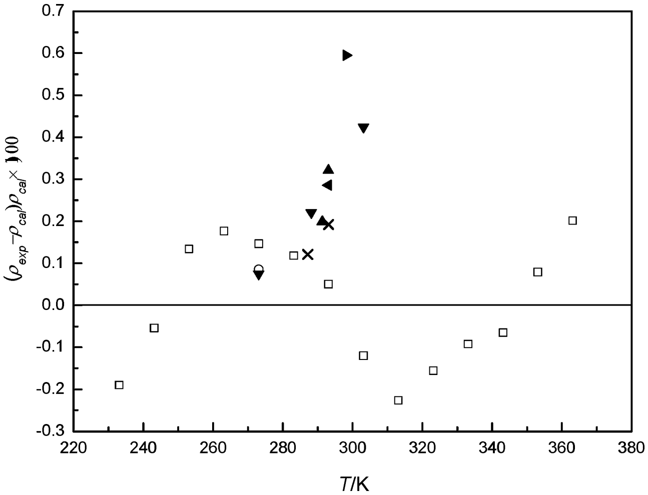

Figure 1. Deviation of experimental density results and literature data for dimethoxymethane from eq 4: □, this work; ▲, Bruhl;[11] ○, Timmermans;[11] ▼, Timmermans and Martin;[11] solid triangle with left-facing point, Le Fevre;;[11] ×, Vogel;[11] solid triangle with right-facing point, Comelli.[12]

decreases with increasing temperature, and A and B are temperature-independent instrument parameters. In this work, the relative measurement method was applied, and because the measurement temperature was far below the critical temperature of dimethoxymethane, k was taken as 1.0. The constant B was determined from the following equation:[7]

$$B = \frac{mghR^4}{64A(L + nR)^2} \tag{3}$$

According to ref 8, in the range of Reynolds numbers $46 \leq Re \leq 1466$, the values of m are 1.08 to 1.16, and the end-correction factor n is 0.57.

In this work, pure water and ethanol were selected as reference liquids to determine the constant A. In this instrument, the flow time of water and ethanol was longer than 900 s at ambient temperature. The constant A was fitted as 4.9672×10^{-10} m^2·s^{-2} with the least-squares method. The details of the apparatus and experimental procedure are given in refs 7 and 9. The uncertainties of the results were estimated to be less than ±1.3% for kinematic viscosity and ±1.8% for dynamic viscosity.

3. Results and Analysis

The experimental density values of saturated liquid dimethoxymethane, measured from (233.15 to 363.15) K, are listed in Table 1 and fitted using the following equation

$$\rho_{\mathrm{r}} = 1.0 + 0.965465\tau^{\beta} + 1.240742\tau^{2\beta} + 0.305478\tau^{1/\beta} \tag{4}$$

where $\rho_{\mathrm{r}} = \rho/\rho_{\mathrm{c}}$, $\tau = 1.0 - T/T_{\mathrm{c}}$, the critical density $\rho_{\mathrm{c}} = 357.26$ kg/m^3, the critical temperature $T_{\mathrm{c}} = 480.60$ K,[10] and the critical exponent $\beta = {}^1/_3$. The uncertainties in the densities were estimated to be less than ±1.0 kg/m^3. As shown in Table 1, the maximum and average deviations between the calculated values and experimental data are 0.22% and 0.13%, respectively. The reason that eq 4 was used was that it could be extrapolated well, although the fitting ability of this equation may as good as that of other equations. There were few density data of liquid dimethoxymethane found in the literature,[11,12] as shown in Figure 1 where the maximum deviation of the experimental results from eq 4 was less than 0.7%.

Table 2 gives the kinematic viscosity ν and the density ρ calculated from eq 4 as well as the dynamic viscosity η. On the assumption that the surface tension effects were

Table 2. Experimental Viscosity Values for Saturated Liquid Dimethoxymethane

T/K	ρ_{calcd}/kg·m^{-3}	υ/mm^2·s^{-1}	η/μPa·s	T/K	ρ_{calcd}/kg·m^{-3}	υ/mm^2·s^{-1}	η/μPa·s	T/K	ρ_{calcd}/kg·m^{-3}	υ/mm^2·s^{-1}	η/μPa·s
218.09	956.8	1.3252	1263.1	273.05	884.9	0.4731	418.3	333.14	800.7	0.2741	220.2
218.09	956.8	1.3227	1263.0	278.05	878.2	0.4424	391.2	333.15	800.7	0.2746	220.2
223.09	950.4	1.1454	1098.7	278.05	878.2	0.4412	391.2	338.15	793.3	0.2656	210.7
223.09	950.4	1.1468	1098.7	283.10	871.4	0.4196	366.9	338.15	793.3	0.2647	210.7
228.10	943.9	1.0236	964.9	283.10	871.4	0.4185	366.9	343.15	785.7	0.2584	201.7
228.11	943.9	1.0271	964.8	288.17	864.5	0.3988	345.2	343.15	785.7	0.2577	201.7
233.10	937.4	0.9064	855.7	288.17	864.5	0.3979	345.1	348.16	778.0	0.2505	193.1
233.10	937.4	0.9084	855.6	293.09	857.7	0.3786	326.2	348.16	778.0	0.2502	193.1
238.11	930.9	0.8214	764.8	293.09	857.7	0.3800	326.2	353.12	770.3	0.2410	185.0
238.11	930.9	0.8225	764.8	298.12	850.8	0.3646	308.6	353.13	770.3	0.2416	185.0
243.14	924.3	0.7496	688.6	298.13	850.8	0.3642	308.6	358.16	762.3	0.2338	177.1
243.15	924.3	0.7481	688.5	303.12	843.9	0.3498	292.7	358.16	762.3	0.2329	177.1
248.14	917.8	0.6844	624.8	303.13	843.9	0.3494	292.7	363.15	754.3	0.2240	169.6
248.14	917.8	0.6849	624.8	308.16	836.8	0.3336	278.1	363.15	754.3	0.2235	169.6
253.13	911.3	0.6300	570.5	308.17	836.8	0.3325	278.1	368.14	746.1	0.2169	162.4
253.14	911.3	0.6322	570.5	313.16	829.7	0.3178	264.7	368.16	746.1	0.2161	162.3
258.12	904.7	0.5832	524.0	313.16	829.7	0.3184	264.7	373.14	737.8	0.2102	155.4
258.15	904.6	0.5852	523.8	318.16	822.6	0.3057	252.4	373.14	737.8	0.2100	155.4
263.07	898.2	0.5351	484.1	318.17	822.6	0.3048	252.4	378.15	729.2	0.2031	148.6
263.09	898.1	0.5347	483.9	323.15	815.4	0.2943	241.0	378.15	729.2	0.2038	148.6
268.09	891.5	0.5028	448.9	323.15	815.4	0.2935	240.9	383.15	720.5	0.1972	142.0
268.09	891.5	0.5011	448.9	328.14	808.1	0.2856	230.3	383.16	720.5	0.1975	142.0
273.05	884.9	0.4712	418.3	328.14	808.1	0.2856	230.3				

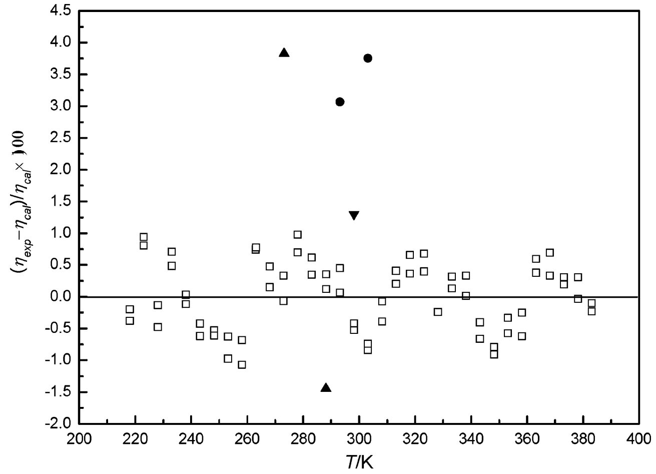

Figure 2. Deviation of experimental viscosity results and literature data for dimethoxymethane from eq 5: □, this work; ▼, Comelli;[12] ▲, Timmermans and Martin;[14] ●, Udovenko.[14]

less than 0.3%,[13] the standard uncertainties of the kinematic and dynamic viscosities were better than 1.3% and 1.8%, respectively. Finally, the dynamic viscosities were correlated as a function of temperature as follows:

$$\log_{10}(\eta/\mu\text{Pa·s}) = -7.40356 + \frac{1291.359}{T/\text{K}} + (2.746\times10^{-2})(T/\text{K}) - (2.95288\times10^{-5})(T/\text{K})^2 \quad (5)$$

where η is the dynamic viscosity. The absolute average deviation and the maximum deviation of the experimental results from eq 5 were 0.45% and 1.07%, respectively. Figure 2 shows the deviations of the experimental viscosity results from eq 5. The viscosity data of liquid dimethoxymethane found in the literature[12,14] are shown in Figure 2. The difference between this work and the results of Comelli et al.[12] is less than 1.5%.

4. Conclusions

The density of dimethoxymethane was measured using a vibrating-tube densimeter at temperatures from (233.15 to 363.15) K, and the viscosity of dimethoxymethane was measured with a capillary viscometer at temperatures from (218.15 to 383.15) K along the saturation line. Density results were fitted using a polynomial with an absolute average deviation of 0.13% and a maximum deviation of 0.22% from the correlated equation. The dynamic viscosity was correlated as a function of temperature. The absolute average deviation and the maximum deviation of the viscosity results from the correlated equation were 0.45% and 1.07%, respectively.

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